

# CONSTRAINING SUSY GUTs WITH COSMOLOGY

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Cosmic strings of the GUT scale, generically formed during the SSB of supersymmetric hybrid inflation, are compatible with the most recent CMB data. The strong constraints on the allowed cosmic strings contribution to the measured temperature anisotropies impose limits on the free parameters of the inflationary models, namely the mass scales and the couplings.

## 1 Introduction

According to the Grand Unified Theories (GUTs), topological defects are expected to be formed during the phase transitions accompanied by Spontaneously Symmetry Breaking (SSB), as the Universe cools down during its expansion. Among the various kinds of local (gauge) topological defects only cosmic strings are allowed; monopoles and domain walls would overclose the Universe, implying that an inflationary era is required after the formation of the harmful defects. Considering all SSB schemes from a large gauge group down to the standard model, cosmic strings, occasionally accompanied by embedded strings, are always left behind after the last inflationary era<sup>1</sup>. However, constraints are also imposed on cosmic strings. More precisely, cosmic strings of the GUT scale should not contribute more than about 10% to the CMB temperature anisotropies<sup>2,3</sup>. This CMB constraint on cosmic strings does not imply that GUT scale cosmic strings are ruled out. It can instead be used to constraint the free parameters (mass scales and couplings) of the inflationary model. We study<sup>4,5</sup> these constraints for F-term and D-term inflation.

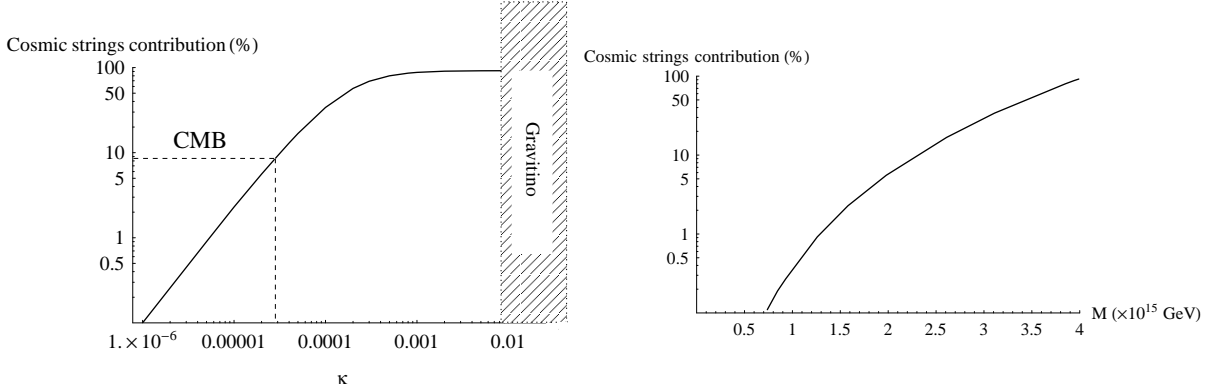


Figure 1: On the left, constraints on the single parameter  $\kappa$  of the model (for  $\mathcal{N} = \mathbf{3}$ ). On the right, evolution of the cosmic strings contribution to the quadrupole anisotropy as a function of  $M$ .

## 2 F-term inflation

F-term inflation is based on the SUSY renormalisable superpotential

$$W_{\text{infl}}^{\text{F}} = \kappa S(\Phi_+ \Phi_- - M^2) , \quad (1)$$

with  $S, \Phi_+, \Phi_-$  three chiral superfields and  $\kappa, M$  constants. Including the one-loop radiative corrections to the scalar potential along the inflationary valley, the effective potential reads

$$V_{\text{eff}}^{\text{F}}(|S|) = \kappa^2 M^4 \left\{ 1 + \frac{\kappa^2 \mathcal{N}}{32\pi^2} \left[ 2 \ln \frac{|S|^2 \kappa^2}{\Lambda^2} + (z+1)^2 \ln(1+z^{-1}) + (z-1)^2 \ln(1-z^{-1}) \right] \right\} , \quad (2)$$

where  $z = |S|^2/M^2 \equiv x^2$ , and  $\mathcal{N}$  stands for the dimensionality of the representations to which the complex scalar components  $\phi_+, \phi_-$  of the chiral superfields  $\Phi_+, \Phi_-$  belong. Now,  $S$  denotes the scalar component of its superfield.

On large angular scales, the main contribution to the CMB anisotropies is given by the Sachs-Wolfe effect. The quadrupole anisotropy, normalized to the DMR-COBE data, has two contributions: one coming from the quantum fluctuations of the inflaton field and another one from the cosmic strings network. The two contributions can be computed numerically for given values of  $\kappa, \mathcal{N}$  and fixing the number of e-foldings. We find<sup>4,5</sup> that the mass scale  $M$  grows very slowly with  $\mathcal{N}$  and it is of the order of  $10^{15}$  GeV. The parameter  $M$  sets the scale of inflation, and the mass scale of cosmic strings formed at the end of the inflationary era. The CS contribution to the CMB is a function of the coupling  $\kappa$ , or equivalently of the mass scale  $M$ . The CS contribution to the WMAP measurements should not be higher than 9%, which implies

$$\kappa \lesssim 3 \times 10^{-5} \times \frac{3}{\mathcal{N}} \text{ with } \mathcal{N} \in \{\mathbf{1}, \mathbf{3}, \mathbf{16}, \mathbf{126}\} \Leftrightarrow M \lesssim 2.2 \times 10^{15} \text{ GeV for all } \mathcal{N} . \quad (3)$$

The gravitino constraint on the reheating temperature results to a weaker upper bound for  $\kappa$ , namely  $\kappa \lesssim 8.2 \times 10^{-3}$ . The CMB and gravitino constraints on  $\kappa$ , as well as the cosmic strings contribution to the CMB data as a function of  $\kappa$ , are given in Fig. 1.

The allowed upper limit on the coupling  $\kappa$  can be increased if we employ the curvaton mechanism, in which case we have one extra parameter, namely the initial amplitude of the curvaton field,  $\psi_{\text{init}}$ . The CMB data can be used to constrain the upper bound on  $\psi_{\text{init}}$ , which depends on the coupling  $\kappa$ . We find  $\psi_{\text{init}} \lesssim 5 \times 10^{13} (\kappa/10^{-2}) \text{ GeV}$ , for  $\kappa$  in the range  $[5 \times 10^{-5}, 1]$ ; smaller values lead to a CS contribution below the WMAP limit. These findings are summarized

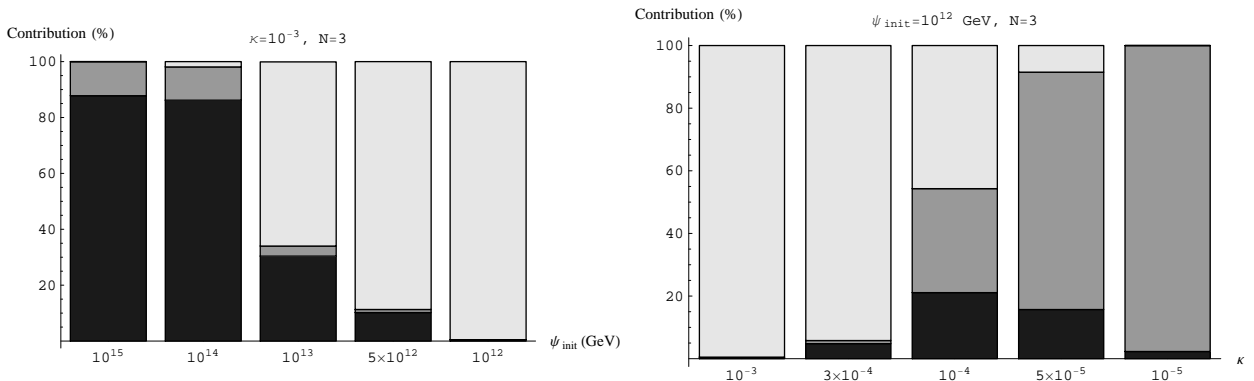


Figure 2: The cosmic strings (dark gray), curvaton (light gray) and inflaton (gray) contributions to the CMB as a function of the the initial value of the curvaton field  $\psi_{\text{init}}$ , and the superpotential coupling  $\kappa$ , for  $\mathcal{N} = 3$ .

in Fig. 2. The Supergravity (SUGRA) corrections can be neglected in the framework of F-term inflation and this is expected since the inflaton field is below the Planck mass by three orders of magnitude.

### 3 D-term inflation

D-term inflation is derived from the superpotential

$$W_{\text{infl}}^{\text{D}} = \lambda S \Phi_+ \Phi_- . \quad (4)$$

D-term inflation requires the existence of a nonzero Fayet-Illiopoulos term  $\xi$ , permitted only if an extra U(1) symmetry is introduced. D-term inflation must be studied in the framework of SUGRA <sup>4,5</sup>, since an analysis within local SUSY results to an inflaton field of the order of the Planck mass or higher.

For minimal supergravity, the effective potential keeping all terms of the one-loop radiative corrections read <sup>4,5</sup>

$$V_{\text{eff}}^{\text{D}} = \frac{g^2 \xi^2}{2} \left\{ 1 + \frac{g^2}{16\pi^2} \left[ 2 \ln \frac{|S|^2 \lambda^2}{\Lambda^2} \exp \left( \frac{|S|^2}{M_{\text{Pl}}^2} \right) + (z+1)^2 \ln(1+z^{-1}) + (z-1)^2 \ln(1-z^{-1}) \right] \right\} , \quad (5)$$

where  $z = [\lambda^2 |S|^2 / (g^2 \xi)] \exp(|S|^2 / M_{\text{Pl}}^2) \equiv x^2$ . The constant term in the potential is identical to the SUSY case, but its first derivative is modified by the factor  $(1 + |S|^2 / M_{\text{Pl}}^2)$ . D-term inflation is trickier than F-term, but it is still possible to solve numerically and find the various contributions to the CMB data.

We note that in the above effective potential we do not consider quantum gravitational corrections, since their computation results to a negligible contribution to the effective potential.

We find that the inflaton field is of the order of  $10 M_{\text{Pl}}$ , for the studied parameter space in  $\lambda$  and  $g$ . The cosmic strings contribution to the quadrupole anisotropy is not constant, nor is always dominant, in contradiction to previously made statements. It depends strongly on the value of the gauge coupling  $g$  and the superpotential coupling  $\lambda$ . We find that  $g \gtrsim 1$  necessitates multiple-stage inflation, since otherwise this inflationary era cannot last for 60 e-foldings, while  $g \gtrsim 2 \times 10^{-2}$  is incompatible with the allowed CS contribution to the CMB measurements. For  $g \lesssim 2 \times 10^{-2}$ , the CMB constraint sets an upper bound to the allowed window for  $\lambda$ , namely  $\lambda \lesssim 3 \times 10^{-5}$ . SUGRA corrections result to also a lower bound on  $\lambda$ , which however is very small.

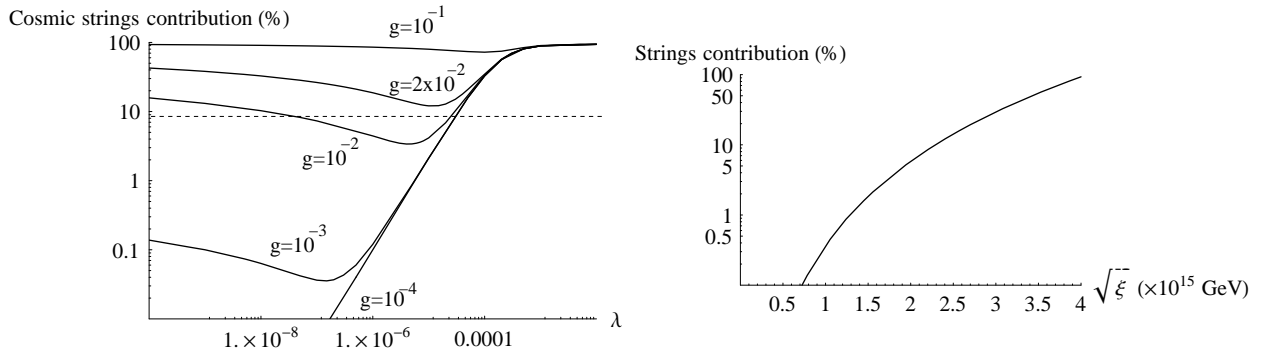


Figure 3: On the left, cosmic strings contribution to the CMB temperature anisotropies, as a function of the superpotential coupling  $\lambda$ , for different values of the gauge coupling  $g$ . The maximal contribution allowed by WMAP is represented by a dotted line. On the right, cosmic strings contribution as a function of the mass scale  $\sqrt{\xi}$ . This holds for all studied values of  $g$ .

The CMB constraint on the couplings of the superpotential can be also expressed as a constraint on the mass scale, which in D-term inflation is given by the Fayet-Iliopoulos term. This constraint reads

$$\sqrt{\xi} \lesssim 2.3 \times 10^{15} \text{ GeV} . \quad (6)$$

Our results are summarised in Fig. 3.

## 4 Conclusions

CMB measurements allow a small but non negligible contribution of cosmic strings to the temperature anisotropies. This results to constraints on the free parameters of supersymmetric hybrid inflation. We thus put bounds on the mass scales and couplings of the superpotential. Our study shows that both F-term as well as D-term inflationary models are open possibilities. Thus, we clearly disagree with previous statements that D-term inflation is ruled out.

## Acknowledgments

It is a pleasure to thank the organizers of the Moriond meeting for inviting me to give this talk.

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